Final Report for Period: 10/2009 - 09/2010 **Submitted on:** 01/04/2011

Principal Investigator: Schatz, Michael . **Award ID:** 0618519

Organization: GA Tech Res Corp - GIT

Submitted By:

Schatz, Michael - Principal Investigator

Title:

Collaborative Research: Institutionalizing a Reform Curriculum in Large Universities

Project Participants

Senior Personnel

Name: Schatz, Michael

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Catrambone, Richard

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Marr, Marcus

Worked for more than 160 Hours: Yes

Contribution to Project:

Post-doc

Name: Kohlmyer, Matthew

Worked for more than 160 Hours: Yes

Contribution to Project:

Postdoctoral research who played a key role in both curriculum implementation and assessment

Graduate Student

Name: Caballero, Marcos

Worked for more than 160 Hours: Yes

Contribution to Project:

Graduate Student in Physics Education Research. Marcos (who goes by his middle name, Danny) plays a key role in supporting the implementation of the Matter and Interactions curriculum at Georgia Tech. Danny plays a key role in carrying out assessment measurements that compare the M&I and traditional curricula.

Name: Bujak, Keith

Worked for more than 160 Hours: Yes

Contribution to Project:

Keith is a psychology graduate student who is working on a think aloud protocol to assess the performance of traditional and M&I students on the FCI

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

North Carolina State University
Partner institution on this collaborative grant

Purdue University
Partner Institution in this Collaborative Proposal

Spelman College
Spelman is a top-notch college for women that is one of the highest rated Historically Black Colleges/Universities(HBCU)in the nation. Since early 2008, we began providing two Georgia Tech undergraduate teaching assistants (funded under this proposal) to work three hours per week at Spelman to assist students with computer modeling projects. Spelman has also agreed to share with us their standardized assessment data from both mechanics and E&M courses.

Other Collaborators or Contacts

Activities and Findings

Research and Education Activities:
PLEASE NOTE: The activities and findings are listing in summary form here; more details are provided in a file (PDF document) attached to this report.

The key activities under this grant were:

? The Successful Implementation of a _Sustainable_ STEM (Physics) Reform Curriculum at Georgia Tech.

? Extensive Measurements of the Impact of Curricular Reform.

? Identification of Future Improvements to the Reform Curriculum:

? Outreach and Dissemination, including a new collaboration on STEM reform between Georgia Tech and Spelman College (a HBCU), the production of two journal papers and the delivery of 7 invited/5 contributed talks/colloquia in local, regional and national venues (universities and meetings).

Findings: (See PDF version submitted by PI at the end of the report)
(1) A Sustainable STEM Reform Curriculum at Georgia Tech: The physics reform curriculum, Matter and Interactions (M&I), has been firmly established as part of the introductory physics coursework at Georgia Tech. The implementation experience at Georgia Tech provides suggestions for improving the odds of sustainable implementation of STEM reform curricula like M&I at other institutions. Anecdotal evidence suggests that successful implementation of M&I at Georgia Tech is causing other universities (e.g., the University of Texas, Austin) to consider adopting the curriculum.

(2) Measurements of the Impact of Curricular Reform: Extensive effort was devoted to measuring quantitatively the performance of students in the M&I curriculum (relative students in a traditional curriculum). Taken as a whole, the results of these measurements were mixed;

nevertheless, these results suggest directions for future work to improve physics instruction. Details of the measurements and sample course materials can be accessed via the Internet: http://phweb.physics.gatech.edu/academics/introcoursecomparison (if you have difficulties with access, please contact Mike Schatz at ms201@mail.gatech.edu)

(3) Future Improvements to Reform Curriculum: Experience with the shortcomings of the M&I curriculum has suggested two avenues of research could lead to very large improvements relative to both the traditional and the current M&I curricula. Those areas are:
(3a) The systematic use of cognitive science methods to devise novel instructional materials to teach effectively principle-based problem solving.
(3b) The tighter integration of computational modeling in introductory physics by means of novel cyberlearning/computational homework exercises.

(4) Outreach and Dissemination: A collaboration between GT and Spelman College (a highly selective HBCU) on the M&I curriculum developed during the course of this grant and is continuing. Work on this grant has resulted in one published and one paper submitted to peer reviewed journals; 7 invited talks/colloquia and 5 contributed talks at colleges/universities and local/regional/national meetings.

Training and Development:

The work under this proposal has supported the training of nine academic faculty and more than 100 graduate students in the presentation and delivery of a STEM (Physics) reform curriculum.

Outreach Activities:

Since Spring 2008, Georgia Tech has provided M&I experienced undergraduates to assist the faculty at the Physics Department of Spelman College, who are teaching Matter & Interactions in their introductory physics courses. The GT undergraduates serve as teaching assistants help Spelman faculty in the teaching of M&I exercises on computational physics (simulation/visualization) in Spelman labs. This arrangement has worked well now for nearly 3 years. The faculty at Spelman continue to report that the visiting TAs have had a very positive impact on student performance and satisfaction.

Journal Publications

Kohlmyer, MA; Caballero, MD; Catrambone, R; Chabay, RW; Ding, L; Haugan, MP; Marr, MJ; Sherwood, BA; Schatz, MF, "Tale of two curricula: The performance of 2000 students in introductory electromagnetism", PHYSICAL REVIEW SPECIAL TOPICS-PHYSICS EDUCATION RESEARCH, p. , vol. 5, (2009). Published, 10.1103/PhysRevSTPER.5.02010

M.D. Caballero, K.R. Bujak, M.A. Kohlmyer, R. Catrambone, M.J. Marr and M.F. Schatz, "Student performance on the Force Concept Inventory: The impact of curriculum", American Journal of Physics, p. , vol. , (2011). In Preparation,

Books or Other One-time Publications

Web/Internet Site

URL(s):

http://phweb.physics.gatech.edu/academics/introcoursecomparison

Description:

This website contains detailed information and measurements comparing two different calculus-based introductory physics curricula: (1) A traditional curriculum, (2) The Matter and Interactions Reform curriculum.

Other Specific Products

Product Type:

Submitted journal paper, Conference paper, 2 posters and 1 breakout session

Product Description:

see file attached to Findings section for more details.

Sharing Information:

see file attached to Findings section for more details.

Contributions

Contributions within Discipline:

This work provides a model for implementing a physics reform curriculum at a large university, including specific suggestions for increasing the odds of implementing a _sustainable_ reform. There is evidence that the GT example is helping contribute to the adoption of the reform curriculum at other universities (e.g., the University of Texas, Austin).

Contributions to Other Disciplines:

The specific suggestions for increasing the odds of implementing a _sustainable_ reform in physics instruction may also be applicable to implementing and sustaining reform in other STEM disciplines.

Contributions to Human Resource Development:

The reform curriculum implemented here provides introductory STEM students with a much needed exposure to computational modeling, which is widely used in 21st century science and engineering.

Contributions to Resources for Research and Education:

See findings attachment for details.

Contributions Beyond Science and Engineering:

Conference Proceedings

Categories for which nothing is reported:

Any Book

Contributions: To Any Beyond Science and Engineering

Any Conference

Collaborative Research: Institutionalizing a Reform Curriculum in Large Universities

Final Report for Period: October 2006-December 2010

(Georgia Tech)

HIGHLIGHTS

- **A Sustainable STEM Reform Curriculum at Georgia Tech:** The physics reform curriculum, Matter and Interactions (M&I), has been firmly established as part of the introductory physics coursework at Georgia Tech. The implementation experience at Georgia Tech provides suggestions for improving the odds of sustainable implementation of STEM reform curricula like M&I at other institutions. Anecdotal evidence suggests that successful implementation of M&I at Georgia Tech is causing other universities (e.g., the University of Texas, Austin) to consider adopting the curriculum.
- **Measurements of the Impact of Curricular Reform:** Extensive effort was devoted to measuring quantitatively the performance of students in the M&I curriculum (relative students in a traditional curriculum). Taken as a whole, the results of these measurements were mixed; nevertheless, these results suggest directions for future work to improve physics instruction. Details of the measurements and sample course materials can be accessed via the Internet: http://phweb.physics.gatech.edu/academics/introcoursecomparison (if you have difficulties with access, please contact Mike Schatz at ms201@mail.gatech.edu)
- **Future Improvements to Reform Curriculum:** Experience with the shortcomings of the M&I curriculum has suggested two avenues of research could lead to very large improvements relative to both the traditional and the current M&I curricula. Those areas are:
    - The systematic use of cognitive science methods to devise novel instructional materials to teach effectively principle-based problem solving.
    - The tighter integration of computational modeling in introductory physics by means of novel cyberlearning/computational homework exercises.
- **Outreach and Dissemination:** A collaboration between GT and Spelman College (a highly selective HBCU) on the M&I curriculum developed during the course of this grant and is continuing. Work on this grant has resulted in one published and one paper submitted to peer reviewed journals; 7 invited talks/colloquia and 5 contributed talks at colleges/universities and local/regional/national meetings.

A Sustainable Reform Curriculum at Georgia Tech:

During the period of this grant, the Matter and Interactions (M&I) reform curriculum was implemented as integral part of introductory physics courses taught at Georgia Tech (GT). Starting with 40 students in Summer 2006, the enrollment in GT M&I courses has grown to approximately 2000 students annually (approximately one-half of the total annual GT physics

enrollment). In 2006, no GT faculty taught the M&I curriculum; now, nine GT faculty (one-fourth of the total GT physics faculty) are experienced M&I instructors.

There are two key characteristics of the GT M&I implementation that helped make the adoption of this STEM reform curriculum occur smoothly without any significant difficulties. First, the reform was phased in *gradually*, thereby allowing sufficient time to develop the infrastructure needed to adapt the curriculum to the local environment of the institution. Second, the reform relied heavily upon the guidance of a local expert, particularly in the early stages of adoption. (In the case of GT, this expert was a teaching postdoc, who was very familiar with the reform; this role could be filled by a resident faculty member at another institution.) The local expert not only directed the development of the necessary infrastructure (e.g., lab equipment procurement and installation, TA training), but also, more importantly, worked closely with faculty to provide invaluable advice and support to ease the faculty's transition to the reform curriculum.

The "smoothness" of the GT M&I implementation helped set the stage, but did not guarantee a *sustainable* adoption. In the PI's opinion, the key reasons why the M&I adoption at GT has long term sustainability are: (a) all GT faculty who have taught M&I now favor the reform curriculum, and (b) the M&I courses are slightly more popular among GT students. In faculty meetings discussing the reform curriculum, all GT faculty with M&I experience have given favorable (in some cases, enthusiastic) reviews of their M&I experience—as a result of these positive testimonials, there is virtually no opposition to the curriculum among the GT physics faculty. Moreover, GT students have been "voting with their feet" during registration; sections of M&I physics tend to fill somewhat more rapidly than sections that teach a traditional physics curriculum.

The GT M&I implementation is helping to generate interest in adopting the reform curriculum at other universities. The PI had extensive discussions about M&I with colleagues at the University of Texas, Austin; subsequently, UT Austin began pilot testing M&I in the past year (2010) and plans to offer more sections of M&I physics in 2011. The PI has been invited to speak about M&I implementation at the University of Georgia and Southern Methodist University, where adoption of M&I is now being considered. Moreover, the PI has had phone conversations about M&I with colleagues at Georgetown University and the University of Michigan.

Measuring the Impact of Curricular Reform

At GT, the substantial effort devoted to measure student performance in M&I curriculum (relative to student performance in a traditional physics curriculum) produced, in general, no compelling case for selecting one curriculum over another; as a consequence, measurement results did **not** play a significant role in the ultimate adoption of M&I at GT. Nevertheless, the measurements did produce a number of interesting results that point to the need for further work to improve the teaching and learning of physics. Specifically,

- Data from Georgia Tech, NC State, Purdue, and Carnegie Mellon show M&I students consistently outperform traditional curriculum students on an electromagnetism concept inventory (the Brief Electricity and Magnetism Assessment (BEMA)) A paper describing these results was published in 2009 in *Physics Review Special Topics: Physics Education Research.* The reasons for this outperformance are not presently understood.
- Data from Georgia Tech students show traditional curriculum students consistently outperform M&I students on a mechanics concept inventory (the Force Concept Inventory (FCI)). Detailed analysis of in-class activities suggests that the performance difference may be due to the effect of time-on-task; in particular, traditional students spend, on average, nearly double the time in lecture and on homework engaged with topics/problems that are directly related to FCI questions. Additionally (and separately), results from "think-aloud" protocol studies suggests that while M&I aims to teach a principle-based approach to problem solving, M&I students do not use this approach when solving FCI problems. One paper describing these results is currently in the final stages of preparation for submission to the *American Journal of Physics.*
- Data from Georgia Tech shows that students in both M&I and traditional curricula show similar (poor) performance on common final exam problems.
- The impact of the M&I curriculum in areas that do not overlap with the traditional physics curriculum (e.g., the impact of computation on student problem solving) remains largely unmeasured.

Future Improvements

The GT experience with the M&I curriculum has revealed two areas where the reform curriculum could be significantly strengthened:

(1) Enhancing student experiences with computational modeling: The current M&I curriculum provides introductory STEM students with a much needed exposure to computational modeling, which is widely used in 21st century science and engineering. Some M&I students readily understand and appreciate the importance of computation; however, we find a large fraction of M&I students tend to view computational modeling as a peripheral activity that should be avoided as much as possible and, in any event, "does not belong in physics". We believe that this perception is reinforced by the current M&I curriculum design that confines the experience of computational modeling to the laboratory. We are currently engaged in developing web-based computational modeling homework that builds on the initial experience of computation in the lab. The use of computational modeling homework communicates a very different message to students; namely, that lab work is just the beginning (not the end) of their use of the models they developed. Our hope is that increased, frequent interaction of students with computation more tightly interwoven into introductory physics (that may, but need not necessarily use the M&I curriculum) will help students begin to see the central role that computation occupies in modern scientific practice.

(2) Helping students become principle-based problem solvers: M&I makes a serious effort to employ the results of cognitive science by presenting introductory physics where fundamental principles are _explicitly_ used to organize hierarchically a deep foundation of detailed factual knowledge. Unfortunately, we find many M&I students do not

fundamental principles when trying to solve physics problems. In particular, (as mentioned above) in a talk aloud protocol study to examine the detailed performance of M&I mechanics students on selected questions on the Force Concept Inventory (FCI), we found most M&I students did not mention (let alone use) a fundamental principle when attempting to solve a problem on the FCI. This experience suggests that effective principle-based instruction requires more than simply reorganizing topics to make fundamental principles explicit; careful attention also needs to be paid to how principle-based instruction is delivered and is utilized by the students. To build such a comprehensive principle-based regimen, we believe cognitive principles must be applied systematically "from the ground up" starting from the core (physics) principles. One possible approach to this process starts with extensive task analyses by cognitive scientists of problems selected by domain experts (physicists) to span the most important subtopics. These analyses, which involve extensive interactions between physicists and cognitive scientists serving as "professional novices" would yield a detailed and explicit unfolding of problem-solving-knowledge of all types (conceptual, declarative, procedural) necessary to proceed from core physics ideas to problem solution. With the results of the task analyses in hand to serve as a "blueprint", instructional interventions could then be devised to teach novices a principle-based approach. At GT, we have assembled a interdisciplinary team of cognitive scientists and physicists, who have submitted proposals to NSF to develop physics instruction (that can be used in but not limited to the M&I curriculum) along the lines outlined here.

Outreach and Dissemination

Since Spring 2008, Georgia Tech has provided M&I experienced undergraduates to assist the faculty at the Physics Department of Spelman College, who are teaching Matter & Interactions in their introductory physics courses. The GT undergraduates serve as teaching assistants help Spelman faculty in the teaching of M&I exercises on computational physics (simulation/visualization) in Spelman labs. This arrangement has worked well now for nearly 3 years. The faculty at Spelman continue to report that the visiting TAs have had a very positive impact on student performance and satisfaction.

JOURNAL ARTICLES:

"Student performance on the Force Concept Inventory: The impact of curriculum", M.D. Caballero, K.R. Bujak, M.A. Kohlmyer, R. Catrambone, M.J. Marr and M.F. Schatz, (in preparation, 2011).

"A Tale of Two Curricula: Performance of two thousand students in introductory electromagnetism", M.A. Kohlmyer, M.D. Caballero, R. Catrambone, R. Chabay, L. Ding, M.P. Haugan, M.J. Marr, B.A. Sherwood and M.F. Schatz, *Phys. Rev. ST Phys. Educ. Res.* **5,** 020105 (2009).

INVITED TALKS AND COLLOQUIA:

"Implementing and Sustaining Curricular Reform in a Large Introductory Physics Course at Georgia Tech," Physics Colloquium, Southern Methodist University, Dec 2010.

"Implementing and Sustaining Curricular Reform in a Large Introductory Physics Course at Georgia Tech," Physics Colloquium, University of Georgia, Sept 2010.

"Reforms and measurements in introductory physics," Physics Colloquium, Spelman College, Atlanta, GA, April 2010.

"Implementing curricular reform in introductory physics courses at Georgia Tech," American Association of Physics Teachers Winter Meeting, Washington, DC, Feb. 2010.

"Implementing and sustaining curricular reform in a large introductory STEM course at Georgia Tech," Project Kaleidoscope-Atlanta Network Meeting, Gainesville State College, Gainesville, GA, Nov. 2009.

"A tale of two curricula: The performance of two thousand students in introductory electromagnetism," 2009 APS March Meeting, Pittsburgh, PA.

"The Life of a Professional Novice: Task Analysis and Instructional Design," Pittsburgh Science of Learning Center (PSLC) seminar series, October 2008

CONTRIBUTED TALKS:

"Reform efforts in introductory physics at Georgia Tech," NSF Eastern SPIN-UP 2010 meeting, East Brunswick, NJ, June 2010.

"Performance of 5000 students in introductory mechanics," Southeastern Section of the American Physical Society meeting, Atlanta, GA, Nov. 2009.

"Performance of 5000 students in introductory mechanics," Southern Atlantic Coast Section of the American Association of Physics Teachers Fall Meeting, Augusta, GA, Oct. 2009 .

"Performance of 5000 students in introductory mechanics," American Association of Physics Teachers Summer Meeting, Ann Arbor, MI, July 2009.

"Performance of 2000 Students on BEMA," Matter and Interactions Summer Workshop, Atlanta, Ga, Aug. 2008.

Collaborative Research: Institutionalizing a Reform Curriculum in Large Universities

Annual Report for Period: October 2008-September 2009

(Georgia Tech)

HIGHLIGHTS

- Numerous informal departmental discussions on introductory physics in late Summer/early Fall 2009 culminated in a Georgia Tech Physics faculty meeting. The meeting was held on 22 September 2009 and focused solely on choosing curricula for the department's large enrollment introductory calculus-based physics courses. A final decision is still pending; however, at present, the mostly likely outcome appears to be the long-term adoption of most (but not all) of the Matter and Interactions (M&I) reform curriculum at Georgia Tech.

- A paper describing student performance (at multiple institutions) on the Brief Electricity and Magnetism Assessment (BEMA) concept inventory has been accepted for publication by the journal *Physical Review Special Topics-Physics Education Research*. The data show M&I students consistently outperform traditional curriculum students on the BEMA.

- Data from thousands of Georgia Tech students show traditional curriculum students consistently outperform M&I students on the Force Concept Inventory (FCI). Results from an initial "think-aloud" protocol study (described briefly in last year's report) were inconclusive; a new study that aims to elucidate M&I students' difficulties with selected FCI questions is in progress.

- Instructional outreach by Georgia Tech to Spelman College, a HBCU that is also using M&I, has continued. Georgia Tech teaching assistants continue to assist Spelman faculty in the teaching of M&I exercises on computational physics (simulation/visualization) in Spelman labs.

Implementation

The long term future at Georgia Tech of the Matter and Interactions (M&I) reform curriculum was subjected to significant departmental scrutiny during late Summer/early Fall of 2009. To facilitate this examination, a website entitled, "Georgia Tech Introductory Physics Course Comparison" was constructed. (The website can presently be accessed at http://www.physics.gatech.edu/academics/introcoursecomparison/ if you have difficulties accessing this link, please contact the PI at ms201@mail.gatech.edu) The website is designed to provide GT faculty with a "one-stop-shop" that summarizes side-by-side comparisons of the GT M&I physics courses with the GT physics courses taught using a traditional curriculum for

both first semester mechanics and second semester electricity and magnetism (E&M). For each semester (mechanics or E&M), the website provides descriptions of each curriculum, sample problems, and three types of data comparing performance: (1) concept inventory results, (2) scores on identical final exam problems administered simultaneously in both curricula, and (3) average final course grades in engineering courses that list introductory physics as a required prerequisite. The website "went live" in early Summer 2009 and, over the course of the summer and early fall, faculty were notified repeatedly of the website's existence. The presence of the website helped stimulate low-level "hallway" conversations about introductory physics well in advance of official discussions in the setting of a faculty meeting.

The GT faculty met on 22 September 2009 solely to discuss the introductory physics curricula. The PI (Schatz) gave a brief (10 min) overview that, in essence, summarized the content of the curriculum comparison website. A spirited faculty discussion ensued around the following key themes:

(1) Over the course of the M&I implementation, seven GT tenured/tenure-track faculty acquired experience teaching the curriculum. All seven were present at the meeting and all gave a generally favorable review of their M&I experience—this had a big impact of the rest of the (19) GT faculty in attendance.
(2) The presence of computation in the M&I curriculum was viewed universally as a significant positive attribute.
(3) For both mechanics and E&M, the data on both common final exam problems and on average final course grades in follow-on engineering courses showed, for the most part, no statistical difference between students in either curriculum. This null result has a similar null impact on the faculty discussions.
(4) Comments on the M&I E&M curriculum by ALL faculty (not just those with M&I teaching experience) were universally favorable; the outperformance by M&I students on the BEMA helped bolster the faculty's favorable impression.
(5) Comments on the M&I mechanics curriculum by ALL faculty (not just those with M&I teaching experience) were more divided, with several faculty questioning whether the M&I mechanics was simply too different from the traditional. The underperformance by M&I students on the FCI was not discussed at length, but helped raise doubts about the usefulness of the M&I mechanics curriculum.

At the meeting's end, the discussion converged toward the idea of adopting M&I E&M for all GT intro. physics courses. For mechanics, several proposals emerged, primarily with the idea of combining elements of both traditional and M&I curricula in a single course. No final vote was taken; however, the faculty were asked directly by the chair if anyone would object to teaching the M&I curriculum. None of the 26 GT faculty present objected. Final decisions on the curricula are expected to be made by mid-October 2009.

In the 2008-2009 academic year, Georgia Tech expanded slightly the implementation of the Matter & Interactions (M&I) curriculum. With a final decision pending on the long term status of M&I at GT, the department decided to increase the number of M&I sections by only one (from 4 to 5) from Fall 08 through Fall 09. Moreover, the number of faculty experienced in M&I remained stable throughout Fall 08 and Spring 09 at 6; however, one additional faculty member began to teach M&I E&M in Fall 09. In Summer 09, M&I introductory physics at Georgia Tech was offered solely in mechanics. In Fall 09, there are a total of 5 M&I sections (2 in mechanics, 3 in E&M) consisting of about 950 students; this represents slightly more than half of the total enrollment in introductory physics during this semester.

Table 1. **M&I courses by semester.**

Semester	M&I mechanics	M&I EM	Faculty w/M&I experience
Summer 06	1 section, 40 students	None	0
Fall 06	1 section, 120 students	1 section, 45 students	1
Spring 07	2 sections, 200 students total	1 section, 150 students	2
Summer 07	None	1 section, 150 students	3
Fall 07	1 section, 150 students	2 sections, 300 students total	4
Spring 08	2 sections, 300 students total	2 sections, 300 students total	4
Summer 08	1 section, 150 students	1 section, 150 students	4
Fall 08	2 sections, 300 students total	3 sections, 450 students total	6
Spring 08	3 sections, 500 students total	2 sections, 300 students total	6
Summer 09	1 section, 250 students	None	6
Fall 09	2 sections, 400 students total	3 sections, 550 students total	7

Assessment

A paper describing student performance (at multiple institutions) on the Brief Electricity and Magnetism Assessment (BEMA) concept inventory has been accepted for publication by the journal *Physical Review Special Topics-Physics Education Research*. The data show M&I students consistently outperform traditional curriculum students on the BEMA. At Georgia Tech, a different concept inventory (the Conceptual Survey of Electricity and Magnetism—CSEM) is currently being administered for comparison to the (large) existing data on the BEMA.

Our primary assessment efforts are now focused on the significant underperformance of M&I students on the Force Concept Inventory. The data on this underperformance are striking as can be seen by examination of the gains between the FCI pre-test and FCI post-test administered in each curriculum (Figure 1). Figure 2, which illustrates an item analysis that compares (raw) relative performance differences, shows traditional students outperform M&I students on virtually every FCI question.

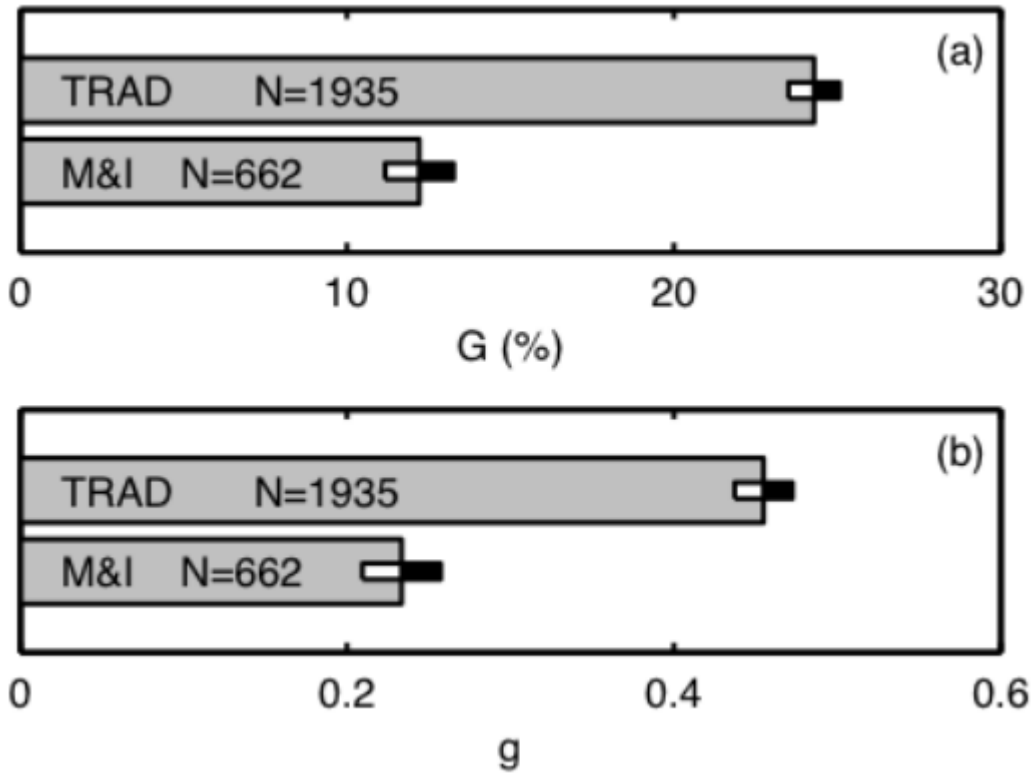

Figure 1. (a) Raw (percentage) gains *G* and (b) normalized gains *g* on the Force Concept Inventory are shown for Georgia Tech students in either the M&I or traditional (TRAD) curriculum. The number of students tested in each curriculum (N) is shown. .

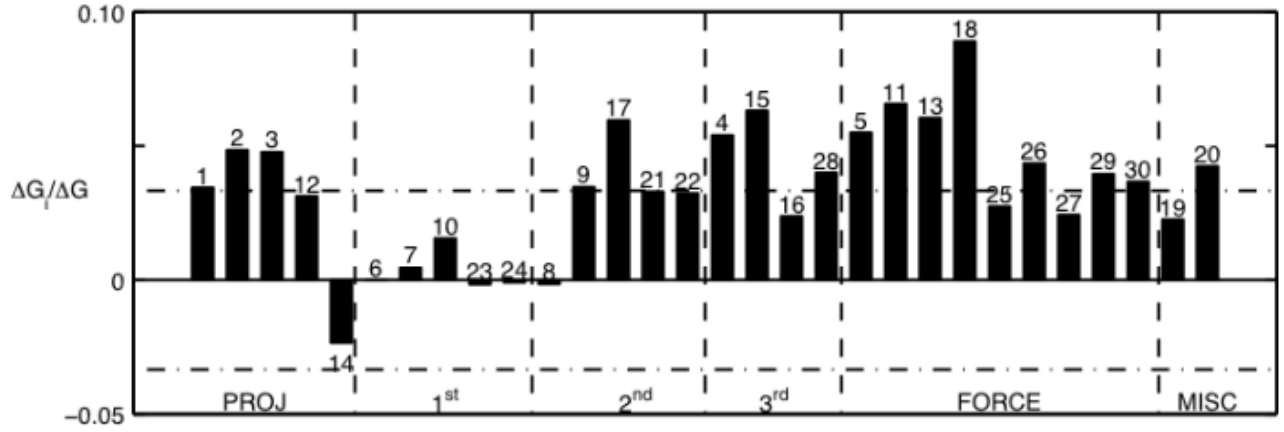

Figure 2. Fractional difference in performance for mechanics subtopics - The fractional difference in performance $\Delta G_i/\Delta G$ between traditional and M&I students at GT is shown for each question on the FCI. Positive (negative) $\Delta G_i/\Delta G$ indicates superior performance by traditional (M&I) students. The numerical labels indicate the corresponding question number in order of appearance on the FCI. The $\Delta G_i/\Delta G$ are grouped together into one of six topics: Projectile Motion (PROJ), Newton's first law (1st), Newton's second law (2nd), Newton's third law (3rd), Force Identification (FORCE), and Miscellaneous (MISC). The horizontal lines (dot-dash) correspond to $\Delta G_i/\Delta G$ = +/- 0.0333, which is the average fractional difference per question on the FCI.

As mentioned in our last annual report, we conducted an initial "think-aloud" protocol study, where paid volunteers from both M&I and traditional courses, in an individual interview setting, were asked to solve ten FCI questions while saying out-loud what came to mind during their solution. Data analysis on this study was performed during the current grant period; in general, the results of this analysis were inconclusive, except for one striking feature. Most of the physics content of the FCI is contained (in M&I language) in the momentum principle (more traditionally known as the impulse-momentum theorem). M&I mechanics places a _very_ heavy emphasis on teaching this principle. Thus, it was very surprising that not one single M&I subject even mentioned the word "momentum" during the think-aloud study. We are currently refining the set of think-aloud questions to include both FCI-based questions and questions that (we hope) may elicit a "momentum principle" response from test subjects; we expect to perform a revised think aloud student using these new questions in the very near future.

Outreach

Since Spring 2008, Georgia Tech has provided M&I experienced undergraduates to assist the faculty at the Physics Department of Spelman College, who are teaching Matter & Interactions in their introductory physics courses. The GT undergraduates serve as teaching assistants help Spelman faculty in the teaching of M&I exercises on computational physics (simulation/visualization) in Spelman labs. This arrangement has worked well now for almost 2 years. The faculty at Spelman continue to report that the visiting TAs have had a very positive impact on student performance and satisfaction.

Dissemination

Over the past year, this work was presented in the following forums:

Talks:

“The Life of a Professional Novice: Task Analysis and Instructional Design.” given by Richard Catrambone at the Pittsburgh Science of Learning Center (PSLC) seminar series, October 2008

"Comparing performance in two mechanics curricula (A 5000 student study)" given by Danny Caballero at the 2009 AAPT Summer Meeting, Ann Arbor, MI.

"A tale of two curricula: The performance of two thousand students in introductory electromagnetism" given by Mike Schatz at the 2009 APS March Meeting, Pittsburgh, PA.

Papers:

"The performance of two thousand students in introductory mechanics", M.D. Caballero, K.R. Bujak, M.A. Kohlmyer, R. Catrambone, M.J. Marr and M.F. Schatz, (2009, in preparation)

"A Tale of Two Curricula: Performance of two thousand students in introductory electromagnetism", M.A. Kohlmyer, M.D. Caballero, R. Catrambone, R. Chabay, L. Ding, M.P. Haugan, M.J. Marr, B.A. Sherwood and M.F. Schatz, accepted by Phys. Rev. ST Phys. Educ. Res. (2009).